NAIC-ID(RS)T-0399-94

NATIONAL AIR INTELLIGENCE CENTER

PROGRESS AND TRENDS OF MULTI-VALUED LOGIC RESEARCH

by

Mu Hou

HUMAN TRANSLATION

NAIC-ID(RS)T-0399-94 6 January 1995

MICROFICHE NR: 95C000028

PROGRESS AND TRENDS OF MULTI-VALUED LOGIC RESEARCH

By: Mu Hou

English pages: 15

Source: Jisuanji Xuebao, Vol. 15, Nr. 1, 1992; pp. 55-60

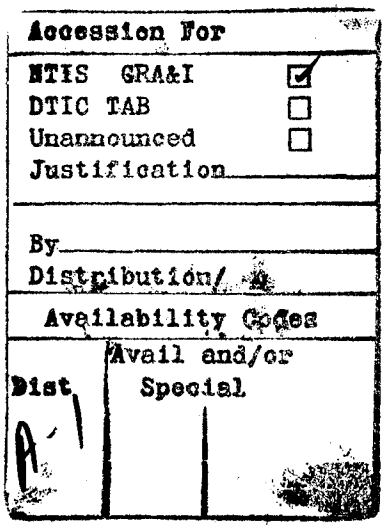
Country of origin: China
Translated by: SCITRAN
F33657-84-D-0165
Requester: NAIC/TATA/J.M. Finley
Approved for public release; Distribution unlimited

PREPARED BY:

TRANSLATION SERVICES
NATIONAL AIR INTELLIGENCE CENTER
WPAFB, OHIO

GRAPHICS DISCLAIMER

All figures, graphics, tables, equations, etc. merged into this translation were extracted from the best quality copy available.



Computer Journal No.1, January 1992

/55*

PROGRESS AND TRENDS OF MULTI-VALUED LOGIC RESEARCH[1]

By Hou, Mu[2]

Abstract

This paper summarizes the progress made in the multi-valued logic research during recent years in China, with emphasis on introducing some representative results. Analyses are made on the recent trend in the multi-valued logic research in the world, with emphasis given to the relationship between multi-valued logic research with respect to molecular computers, optical computers, and artificial intelligence, etc.

1. INTRODUCTION

The idea of multi-valued logic can be traced back to ancient times, but it was in '20's of the 20th century when Polish logicist J. Lukasiewicz and the U.S. mathematician E. L. Post independently suggested it. In '50's of the 20th century during the early development period of electronic computers, a number of researchers tried to use multi-valued logic in solving some practical problems, facing computer science and processing. In 1958 the USSR Moscow University built the world's first 3-valued computer to obtain

---

* Numbers in margins indicate foreign pagination. Commas in numbers indicate decimals.

[1] This paper was received on March 5, 1990. Mr Mou Hu is a professor at Shanghai Institute of Railway Technology, Head of the Department of Computer Engineering, and Chairman of the Chinese Computer Science Society Multi-Valued Logic Research Specialists Committee. His principal research interests at present are in multi-valued logic, error-tolerant computation, and numerical system CAD, etc.

[2] Dept. Computer Engineering, Shanghai Institute of Railway Technology, Shanghai 200333.

pioneering research results. As the year of 1971 started, sponsored by IEEE Computer Science Society, every year the international multi-valued logic science conference has been held. Thus this branch of computer science technology which emphasized multi-valued logic had already received universal attention of the world.

Looking back through history, one finds that the development of multi-valued logic research has not always had smooth sailing. The early stage in multi-valued logic research was mainly aimed at replacing the 2-valued numerical system (2-valued computers) by the use of multi-valued numerical systems (multi-valued computers). However, up to now the binary digital system still occupies the dominant position. Does this mean the multi-valued logic has no life any more? Of course not, analyzing a little bit, one can easily find that in recent years the multi-valued logic research has achieved many results, and the conclusion is that multi-valued logic research has acquired a new characteristic for a new purpose in its development. The new characteristic of multi-valued logic is that it has penetrated many branches of computer science. The new purpose of multi-valued logic is to find a way of solving some practical problems for computer science technologies. This new characteristic and new purpose are presenting multi-valued logic a powerful new life.

What multi-valued logic has already been applied to and what in the future multi-valued logic can be applied to in various branches of computer science may include: Artificial intelligence, error-tolerant computation, numerical system CAD, the numerical system testing, the switch theory, a new generation of computing systems, VLSI and artificial neural networks, etc.

2. RESEARCH DEVELOPMENTS IN OUR NATIONAL MULTI-VALUED LOGIC RESEARCH

Progress in multi-valued logic research in our country (China) during recent years has been very swift. The Specialists group of the Chinese computer science society, directly affiliated with the multi-valued logic group has already organized 4 sessions of nationwide seminars for multi-valued logic science, respectively in 1984, 1987, 1988 and 1989 at Hwa-Nan Institute of Technology, Chung-Qing University, Shanghai Institute of Railway Technology and Han-Zhu University.

Our influence in the world multi-valued logic science communities has become ever more important. From the year 1981 on, at every IEEE International Multi-Valued Logic Science Conference, research papers due to our researchers have been published. Both in 1985 and 1986, the number of papers presented by our national researchers to the international yearly conferences occupied 2nd place, only next to those from the U. S. A. Thanks to the efforts of the specialists committee, in 1989 our country (China) sponsored the 19th IEEE international multi-valued logic scientific conference, and carried it out very smoothly. In this conference, the number of selected papers, due to our national researchers, occupied the first place in displaying the vitality of multi-valued logic research in our country.

Below, most representative accomplishments made in our country on multi-valued logic research are shown. (For the detailed materials, one may refer to the collected papers of the 4th national conference or the IEEE international multi-valued logic scientific conference.)

1. 4-valued logic and star-computation method [1]

Set B_2 as the 2 elements "0" and "1" of Boolean algebra, then the direct product B_2 X B_2 is also a Boolean algebra to become B_4. By expressing the elements of B_4 as θ = (0,0), D = (0,1), $\overline{D}$ = (1,0) and I = (1,1), one constructs a kind of 4-valued logic. The Star-computation method is a computing method to find the conditions of the derived value D (or $\overline{D}$) for the derived function. Because D or $\overline{D}$ reflect the logic variation of the functional value, by use of the star-computation method one can study all sorts of varying, dynamical and transformational situations.

Below are 4-valued logic and a few applications of the star-computation method:

(1) Formation through testing of assembly circuits and procedure circuits. If one splits a vector into 2 components to set them up as a normal value and a breakdown value, then one can find the testing unit for the breakdowns inside a circuit by use of the star-computation method.

(2) Formation of dynamics through testing. For some redundant circuits, any breakdown in the redundant lines cannot be inspected with traditional methods. However if a redundant line in a circuit is used to eliminate some logic venture, one can use 4-valued logic and the star-computation method to pass an inspection to check out whether there is a venture or not, in distinguishing circuitous normal state or breakdown state, and thus one checks out the breakdown in redundant lines which cannot be checked by a static method.

(3) Transformation Logic. One may interpret θ and I of B_4 as "No" and "Yes", and interpret D as the "negative-to-positive transformation", while $\overline{D}$ as the

"positive-to-negative transformation". In this way one can build the base of the transformation logic of B_4. By use of transformation, one can study all kinds of varying and transforming phenomena.

2. The completeness theory [2] of a multi-valued function [2]

Since the '40's, the structural theory of a multi-valued logic function has always been the center of attention in multi-valued logic, and it is one of the very active subjects. One of the most basic and important problems in the structural theory of multi-valued functions is the problem of judging the completeness of the K-value functional group. The final solution of this problem depends on how to determine the maximum closed group in the K-value functional group. In this area of research our national researchers play a leading role in the world. For instance, in the famous Rosenberg theorem of the multi-valued logic theory, important conclusions were obtained by our national scholars.

3. Social Diagnosis [3]

Social diagnosis utilizes the diagnostic method for computer systems in transplanting it to certain social members in order to make judgement on them. The model divides humans into 3 classes: Good liars and criminals. The diagnostic method is to use the testimonies from each member, made on other members, to analyze and determine which one is a good human, which is a criminal and which one is a liar. The adopted logic is a 3-valued one. Social diagnoses can be used as an analytic tool in breaking a case and thus attract attention in the area of public safety.

4. Multi-valued collective circuit and its application [4,5]

(1) A multiple Element Logic (DYL) circuit sequence is one kind of continuous logic circuits; that is, base number R grows rapidly as to pass by even infinity. Such collective circuits have already been used in the telephone systems and electronic instruments and have achieved some practical applications.

(2) The 4-valued DYL circuit has already been used in one kind of multi-valued logic telephone system (MDA-016 Model). Such a telephone system is one type of the exchangeless controlled systems, and a multi-purpose distribution type of automatic internal line telephone system. The system adopts 4 valued logic to carry out calls and uses the continuous value logic circuits as speech-sound control circuits.

(3) The multi-purpose multi-valued logic collective circuit has already been successfully developed and thus received patent rights. It is equipped simultaneously with the numbers and the processing capability of simulated signals, and it is either a totally fixed multi-purpose multi-valued matrix collective circuit or a semi-fixed multi-valued logic matrix collective circuit. The circuit adopts a shared technology of NMOS and DYL. It can be widely applied in some real-time control systems, fuzziness control systems, instrument panels and household electric appliances, etc.

5. Logic Value Redundancy [6,7]

The redundancy technology can be classified as hardware redundancy, software redundancy, time redundancy, and information redundancy. When the information is increased by a few positions, it creates an information redundancy, which is well known error-correcting figures. An information redundancy is a form which is materialized through some excessive increase in the base numbers, and it is called the logic value redundancy. A logic value redundancy is a kind of a scheme to use a 3-valued logic circuit in a bivalued system. Thus during this time, in the system there is a redundancy logic value and it can provide various useful properties.

Below, are a few applications of the logic value redundancy:

(1) From 3, pick 2-valued self-correcting logic systems. Such kind of system is constructed from some special 3-valued gate-circuit. The logic value collective of the system is {0,1/2,1}, where 0 and 1 are the work-logic values while 1/2 acts as the breakdown indicator value. By going through a special design, the system of choosing 2 values out of 3 can provide a breakdown-correction with one of 3 characteristics, namely error-tolerance, total self-correction and failure-insurance, and thus it has greatly improved reliability, testability and safety of the system. Success in this subject attracted a lot of attention from the international multi-valued logic scientific communities, and it was included in the renowned publication of the international multi-valued logic science ---<<Computer Science and Multiple-Valued Logic: Theory and Applications>> (Edited by D. C. Rine).

(2) A 3-valued sweeping design of the testability of a numerical system. When the adoption of a 3-valued time-signal is made in a numerical system, it not only acts on a general time-signal, but can also transmit a mode-selecting signal, and thus it allows one to discard the mode-selecting line from the sweeping design of the testability, to reduce the connecting complexity of the collective circuit and economize the purposes of the core-chip.

(3) Sub-threshold 3 valued testing technique. It is a logic value which is being used in testing the fallout from a numerical circuit. It works in the numerical circuit of a 2-valued state to carry out the testing of the fallout from the computer by transforming itself into a sub-threshold 3-valued circuit, and at the same time it carries out the circuit-testing as well. Such a testing method does not require one to go through the testing-mode and thus can reduce the cost of testings.

6. Intermediary Logic [8]

At first intermediary logic was created to be a theoretical base for fuzzy mathematics, but soon it became a new logic theory on its own right after it had been formulated. Its main difference from classical logic is in the derivation of the intermediary principles. The so-called intermediary principles are unconditionally to recognize the existence of intermediary objects in any set of the for-or-against confrontation. From the technological point of view, one can say that when one gets involved in the areas of thought, reasoning, judgement and decision, one cannot avoid getting involved with some intermediate phenomena, namely intermediary objects. Thus intermediary

logic can play an important role in technological developments. For instance, for the development of a new generation of computers, such as for expert systems, the mode recognition, and the large system theory, etc. one can always utilize intermediary logic.

7. Comparative logic and the transport function theory [9,10]

(1) Comparative logic and double-entry type circuits. Sometimes one wants to interpret various basic elements of a circuit from comparative angles, but does not want to just limit oneself to the switch-action. Consequently one ends up comparing the computations or comparing the logic gates. Because one can compare computations to clarify the working characteristics of the switching devices, therefore one can simplify the circuitous structures and improve the functions by use of comparative logic in the design of any numerical circuit.

(2) The transport function theory and MOS circuit. In the transport function theory, there are 2 kinds of variables --signal variable and logic variable. The value-number picked by the signal variable is taken as the base number of the system. Because the logic variable expresses 2 kinds of switching values, the selected value is thus either T or F. Between these 2 kinds of variables, by use of a new computation, one can establish a connecting system. The first kind of the new computation is the threshold-comparing computation, used to describe the matrix-end signal of the MOS tube to determine the physical process of the switching state of the MOS tube. The 2nd kind of the new computation is the transport computation as well as the parallel computation, being used to describe the

switching state of the MOS tube network in the physical process, controlling the source signal transport. The transport function theory can be used to direct the MOS circuit design.

8. Multi-valued spectrum technology [11]

The multi-valued spectrum technology is a technique to take an ordinary basic number as the deviation data of R and to transform it into some other data region. In the multi-valued spectrum technology, our national researchers have contributed a lot, such as the Zhang-Hartley transformation, named after one of us, which is being used in the parameter spectrum of multi-valued logic design or some multiple-term Fourier transformations, etc.

9. ECSA theory and switch-level algebra [12,13]

(1) ECSA theory. It was first proposed by Hayes to become the foundation of the CSA theory and developed into a new switch theory. From the collection of basic logic values $V_5 = \{0.1/2,1,U,Z\}$ and the propagation logic collection V_{4n+1}, one defines the contact computation, the switch computation and the attenuation computation. This kind of a new switch theory can be used in the analysis and synthesis of the 2-valued and 3-valued MOS circuits.

(2) Switch-level algebra. It was formulated based on the CSA theory, and came out to become an algebraic system on the switch-level to describe the structure of a numerical system and the behavioral algebraic system --- switch-level algebra. In the study of switch-level algebra, one can describe on the gate-level the relationship between the structure of a numerical system and behavioral Boolean algebra, as well as 2 kinds of transformation methods for

algebraic expressions. A new routine and tool are thus provided for the analysis of numerical systems and for the design automation.

The above introduction is a part of the accomplishments, contributed by our national scholars in the area of the multi-valued logic research. Moreover, our national researchers have also contributed a lot in other areas, such as fuzzy reasoning [14], multi-valued error-correcting codes [15], multi-valued storage circuits [16], fuzzy controllers [17], etc., but due to the limit of the pages here, they cannot be all introduced.

3. THE TREND OF MULTI-VALUED LOGIC RESEARCH

At present in the world, the trend in multi-valued logic research is even more intimately tied with all the branches of computer science technology. Among them, most attention should be given to the relationship between the multi-valued logic research and all the pre-existing areas of computer science technologies. Below they will be summarily introduced.

1. Multi-valued logic and molecular computers

At present computer science technology is about to approach its physical limit, and application of computers is getting more and more complex every day. Under such conditions, a high level of information processing techniques becomes more and more important. Now the bio-information process systems satisfy the processing requirements of the parallel distribution format and are suggested to be the possible routes one should take. Such a system suggests a large scale of parallel processing in the

level of cellular and molecular activities, with a high degree of efficiency. Consequently, one of the attractive future structures of information processing systems is a molecular computer system.

In the biological system, many chemical reactions exist due to the intermediacy of enzyme protein. The active substance is called substrate. One of the important characteristics of the enzyme is uniqueness; that is, one kind of enzyme can only catalyze one particular reaction, and at most it can only catalyze the same characteristic reaction. If the logic value of a multi-valued logic system can be expressed by the multifarious property of a substrate, then the uniqueness property can be very useful for the multi-valued recognizing function. Thus a molecular computer has a close relationship with a multi-valued logic.

Some Japanese researchers made a suggestion in a paper [18] on some kind of model for a molecular switch-device. By use of such model one can construct a kind of collective logic network called a new type of logic network. Its characteristic is in the high information density, high degree of parallelism and is ready to be developed into a system which can process extremely high quality information.

2. Multi-valued logic and optical computers

Recently, developments in optical computers received more and more attention. However, at the beginning it was to apply optical system to simulate computations, and thus research and development were mostly in optical simulation processors. At present, research in this direction is turning toward optical numerical computation. However in optical numerical computers, the adopted idea is also a

2-valued logic, because one has to consider the switch capability, and thus efficiency has been rather low and thus the adopting optical computers of multi-valued logic started to receive attention [19]. According to the reports, the Japanese Industrial Technological Center, Institute of Electronic Technology carried out studies to replace 2-valued logic by some multi-valued logic for the optical devices, and already succeeded in manufacturing some new equipment to carry out the optical computations with 3-valued logic. Such equipment is equipped to raise the computation speed of the optical information processing, to reduce the distribution lines, lessening the number of parts, shrinking the area of chip surfaces and capable of handling more information quantities, and a lot of other characteristics.

3. Multi-valued logic and artificial intelligence

Application of multi-valued logic to artificial intelligence is a multifarious affair. At present prominent is the application of multi-valued logic to the language of artificial intelligence and the application of fuzzy logic to expert systems.

As for the application of multi-valued logic to the language of artificial intelligence, one can start out with the Japanese research on the 5th generation computers. In the 5th generation computers the logic processing design language PROLOG is taken as its core language. Furthermore the PROLOG language is actually based on classic one-step logic, but only its structural parts are being used, and thus essentially it belongs to intuitive logic. Moreover, at present there have been a few new logic procedure design languages, and their basis is not ordinary classical logic.

The literature [20] shows the studies on the logic procedure design and its relationship with multi-valued logic. In it, it points out that in the research on logic procedure design for the true value preservation area in knowledge storage, MIT artificial intelligence-research lab adopts 3 values but not 2-valued speech-commanded computations. For instance, if there is a fact which has not been proved to be either absolutely true or absolutely false, it can still be not contradictory to the other existing facts, and then at this time one chooses, beside "True" or "False", the third value "Unexclusive".

As for fuzzy logic which was applied to the expert system reasoning computers, namely fuzzy inference, it has already been accepted by a lot of people, but it will not discussed here.

4. CONCLUSION

Research on multi-valued logic has become more and more intimately related to a lot of branches of computer science technology, and without any doubt it will contribute to the activities in some new approaches to solve some practical problems in computer science and manufacturing.

Research on multi-valued logic in our country has been making rapid progress, and accumulated quite impressive results. This author recognizes that research in multi-valued logic in our country should place its emphasis in 2 directions. One direction is to promote multi-valued logic and computer science technology to various research on the closely related connective systems of various existing sciences, and the other direction is to emphasize various research on practical applications of multi-valued logic, to

promote our national multi-valued logic research to a new higher ground.

REFERENCES

[1] 陈廷槐,四值逻辑与星算法,计算机学报, 2: (4)(1979).

[2] 罗钟楷,多值逻辑中所有极大封闭集之确定问题,数学学报, (1)(1980).

[3] Jie Xu and Tinghuan Chen, Society Diagnosis (IV), Proc. IEEE ISMVL-89, 1989.

[4] 王守觉,连续逻辑为电子线路与系统提供的新手段,电子学报,14: (5)(1986).

[5] Lin Weiping, Zheng Qilun and Huang Guanguang, A Semi-Custom Technique Realizing Nondestructive Information Processing, Proc. IEEE ISMVL-88, 1988.

[6] 胡 谋,多值逻辑在 VLSI 设计与测试中的若干应用, 电子学报, 17: (6)(1989).

[7] 胡 谋,一种基于三值电路的 FT-TSC-FS 二值数字系统,中国科学 (A 辑), (8)(1985).

[8] 朱梧槚、肖奚安,中介公理集合论系统 MS, 中国科学 (A 辑), (2)(1988).

[9] X. Wu, X. Chen and S. L. Hurst, An Investigation into Ternary Comparison Operators, *International Journal of Electronics*, 64:(6)(1988).

[10] 吴训威、陈倍雄,基于传输函数理论的四值 *CMOS* 电路,中国科学(A 辑),(5)(1989).

[11] G. Zhang, Two Complete Orthogonal Sets of Real Multiple-Valued Functions, Proc. IEEE ISMVL-84, 1984.

[12] 胡 谋, ECSA 理论及其应用,中国科学(A 辑), (1)(1988).

[13] Mou Hu, A Multiple-Valued Algebra for Modeling MOS VLSI Circuits at Switch-Level, Proc. IEEE ISMVL-89, 1989.

[14] X. -H. Liu, K. -Y. Fang and J. -P. Tsai, The Interpretation of Fuzzy Reasoning in Operator Fuzzy Logic, Proc. IEEE ISMVL-89, 1989.

[15] Xiao Guozhen, P-Valued Logic and Error-correcting Codes, *Journal of Applied Science*, 5: (3) (1987).

[16] X. Xu, S. Li and Z. Cui, A New Current-Mode Multi-Valued Storage Circuit, Proc. IEEE ISMVL-89, 1989.

[17] P. Wang, H. Zhuang, J. Zheng, Z. Zhuang and P. Zeng, Programmable Fuzzy Controller-A Hardware System Based on Fuzzy Logic, Proc. IEEE ISMVL-89, 1989.

[18] M. Kameyama and T. Higuchi, Prospects of Multiple-Valued Bio-Information Processing Systems, Proc. IEEE ISMVL-89, 1989.

[19] R. Arrathoon, Optical Multiple-Valued Logic and Multiple-Class Discrimination, Proc. IEEE ISMVL-89, 1989.

[20] D. C. Rine, Some Relationships Between Logic Programming and Multiple-Valued Logic, Proc. IEEE ISMVL-86, 1986.

DISTRIBUTION LIST

DISTRIBUTION DIRECT TO RECIPIENT

ORGANIZATION	MICROFICHE
B085 DIA/RTS-2FI	1
C509 BALLOC509 BALLISTIC RES LAB	1
C510 R&T LABS/AVEADCOM	1
C513 ARRADCOM	1
C535 AVRADCOM/TSARCOM	1
C539 TRASANA	1
Q592 FSTC	4
Q619 MSIC REDSTONE	1
Q008 NTIC	1
Q043 AFMIC-IS	1
E051 HQ USAF/INET	1
E404 AEDC/DOF	1
E408 AFWL	1
E410 AFDTC/IN	1
E429 SD/IND	1
P005 DOE/ISA/DDI	1
P050 CIA/OCR/ADD/SD	2
1051 AFIT/LDE	1
P090 NSA/CDB	1
2206 FSL	1

Microfiche Nbr: FTD95C000028
NAIC-ID(RS)T-0399-94